

**Matt Grob**

Executive Vice President, Qualcomm Technologies, Inc.  
and Chief Technology Officer, Qualcomm Incorporated

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# The Road to 5G:

## Providing The Connectivity Fabric for Everything

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**QUALCOMM®**



# Evolution of the Internet

Yesterday



Today



Tomorrow





# Providing the connectivity fabric for everything



Human communication



Scaling to connect virtually anything, anywhere

Devices as end-points



New and intelligent ways to connect & interact

Best effort data services



Also, new kinds of control & discovery services

Disparate networks



Convergence of access, spectrum types, services

**Requires a new  
connectivity  
paradigm**

# Mobile has made a leap every ~10 years

Qualcomm has played an increasing role in fueling these leaps

1990s



**2G**

Digital  
voice

2000s



**3G**

Mobile  
broadband

2010s



**4G**

Faster and  
better

# 5G

## Connecting

new industries  
and devices

## Enabling

new services

## Empowering

new user  
experiences

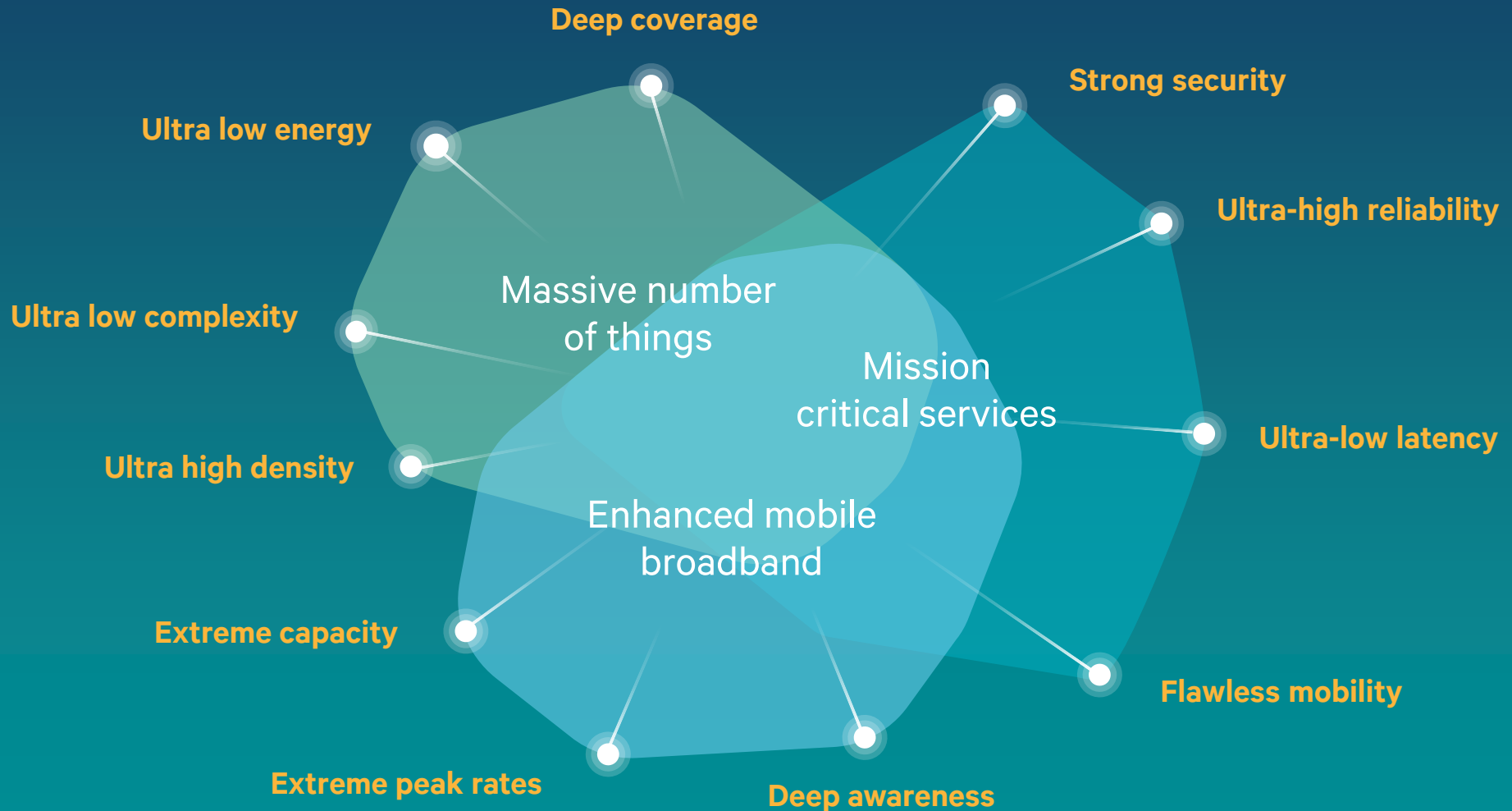
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Scalable

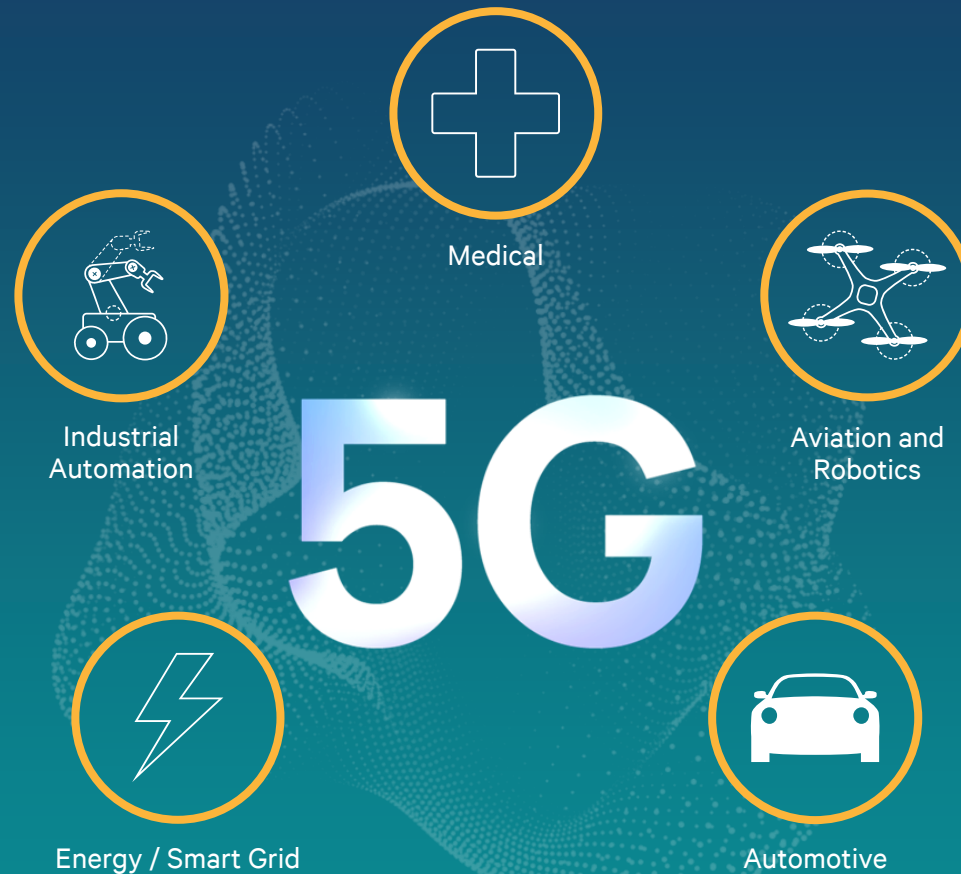
Edgeless

Unified

# 5G will be scalable across an extreme variation



# New ultra-reliable, low-latency, mission critical services



## High Reliability

Extremely low loss rate

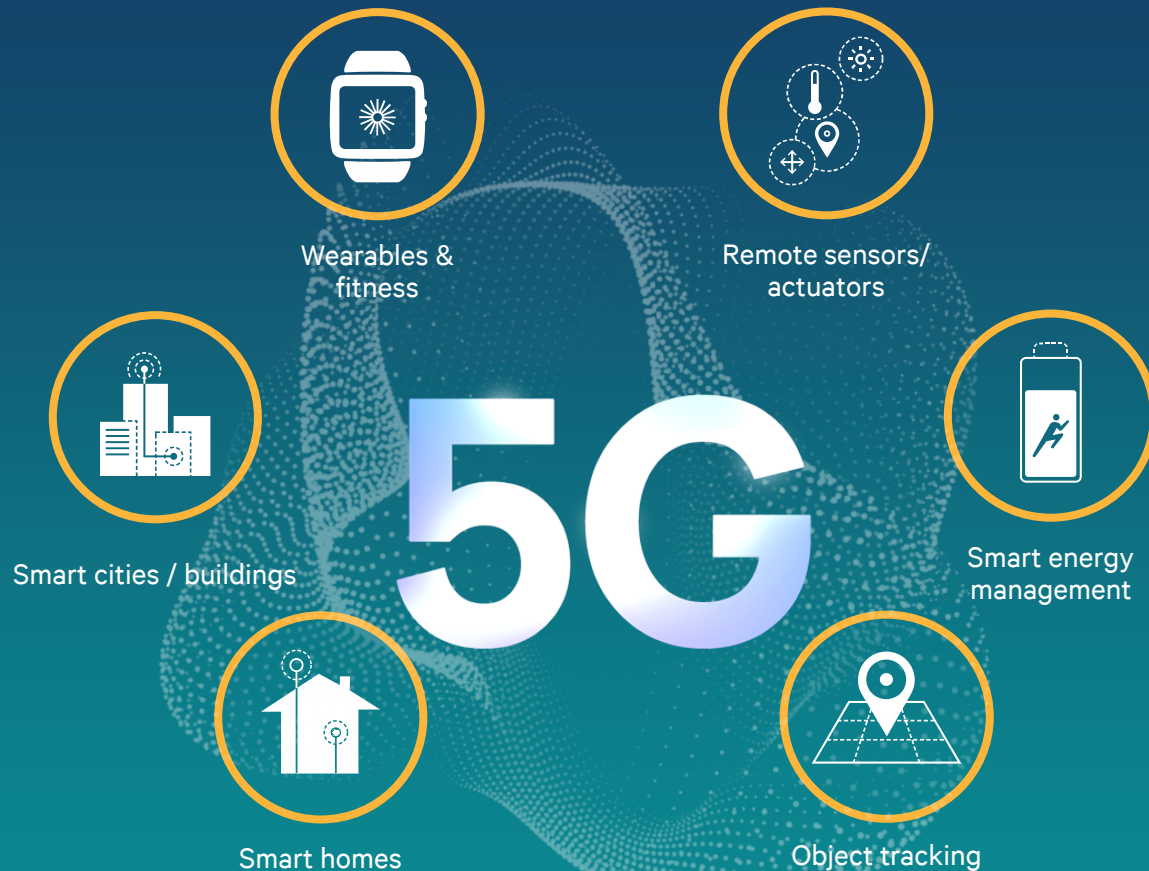
## Low Latency

Down to 1ms e2e latency

## High Resilience

Multiple links for failure tolerance and mobility

# Scaling down to connect low cost 'things'



## Power Efficient

Multi-year battery life

## Low Complexity

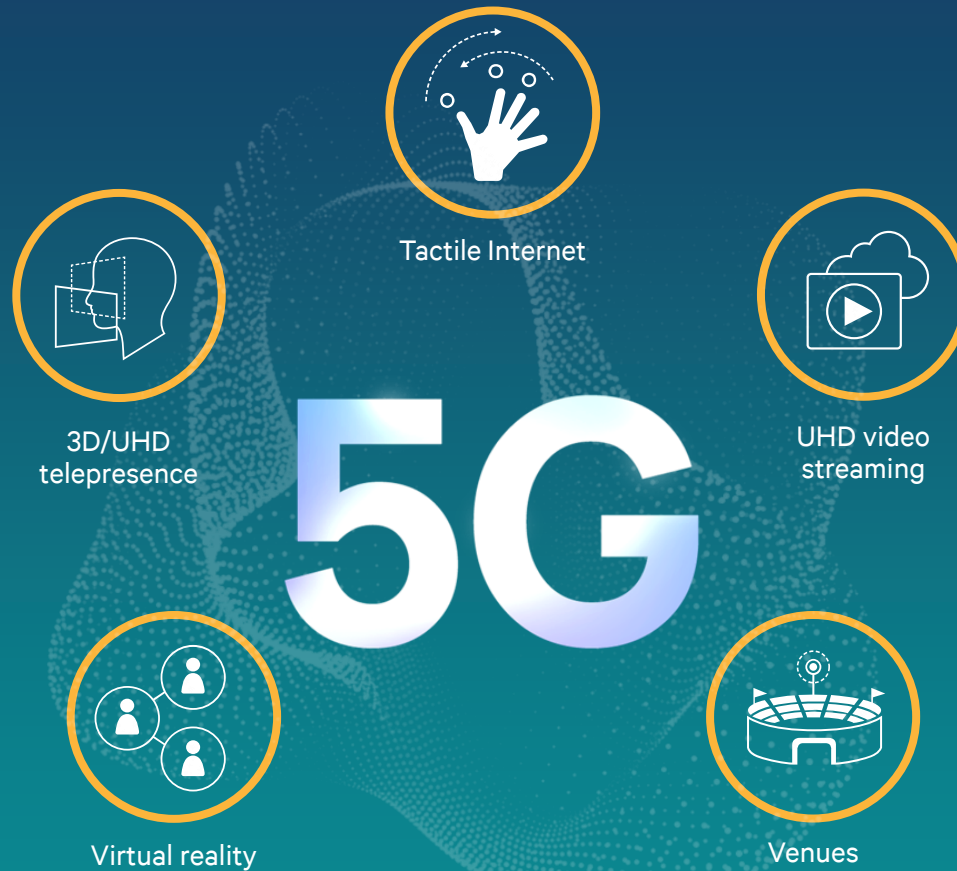
Low device and network cost

## Long Range

Deep coverage



# Scaling up to extreme mobile broadband



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**Extreme Throughput**

Multi-Gbps

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**Low Latency**

Down to 1ms e2e latency

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**Uniform Capacity**

Regardless of proximity to tower

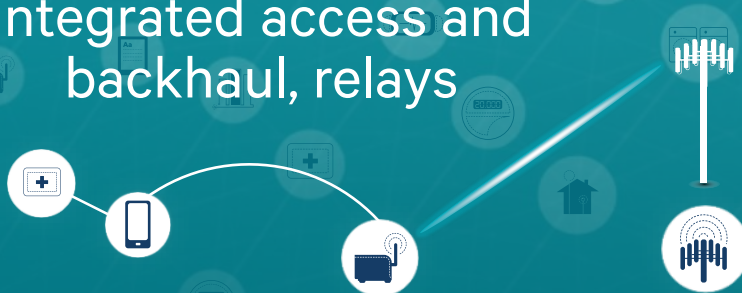
# Multiple enablers toward edgeless connectivity

Uniform experiences—coverage, mobility, capacity—with no perception of ‘cell edges’

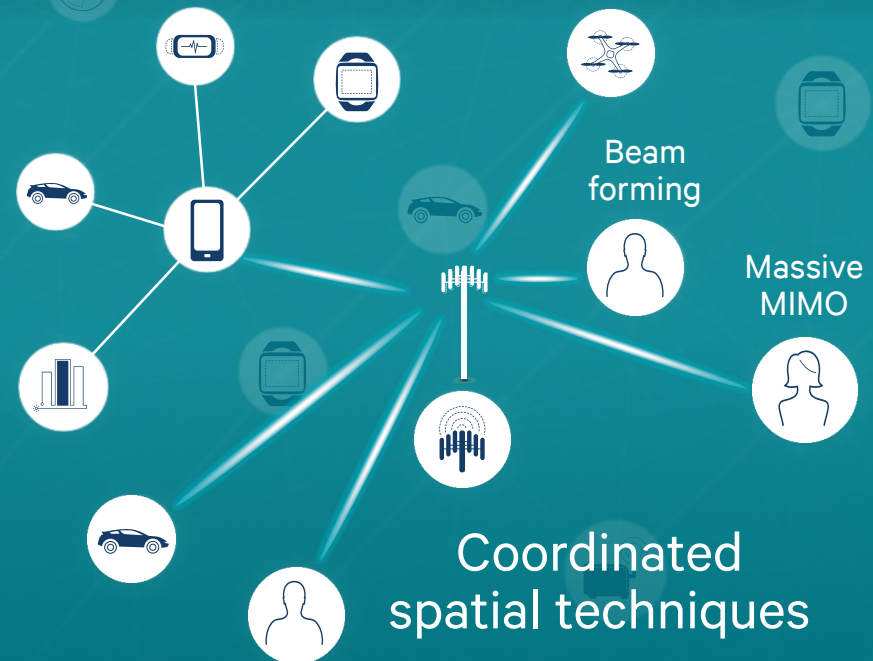
Multi-hop to  
extend coverage



Integrated access and  
backhaul, relays



Device-to-device discovery  
and communications



# A unified, more capable 5G platform for the next decade

Configurable for specific services, verticals, deployment scenarios or phased rollout

## Unified Air Interface—a common framework

Wide area IoT

Mobile Broadband

Ultra-reliable Control

## Multi-connectivity—including 4G and Wi-Fi

## Scalable, multi-access core network

Flexible deployment, services, security and subscription models

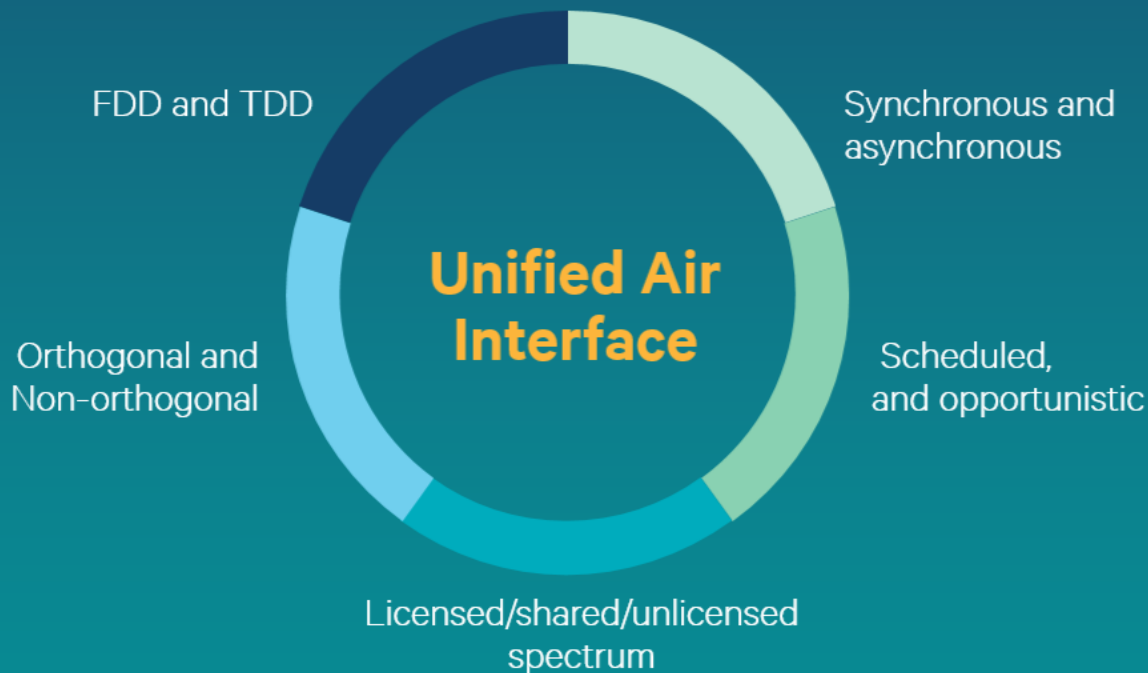
Residential

Venue /  
neutral hosts

IoT  
Vertical

Traditional operator; mobile broadband,  
multiple IoT verticals, mission critical services

# 5G will build on the OFDM family foundation



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OFDM family excellent for mobile broadband and other use cases, e.g. ultra-reliable services

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Other non-orthogonal methods may be proposed for specific use cases, e.g. IoT uplink



# Unified 5G design across spectrum types and bands



**Below 1 GHz:** longer range, massive number of things

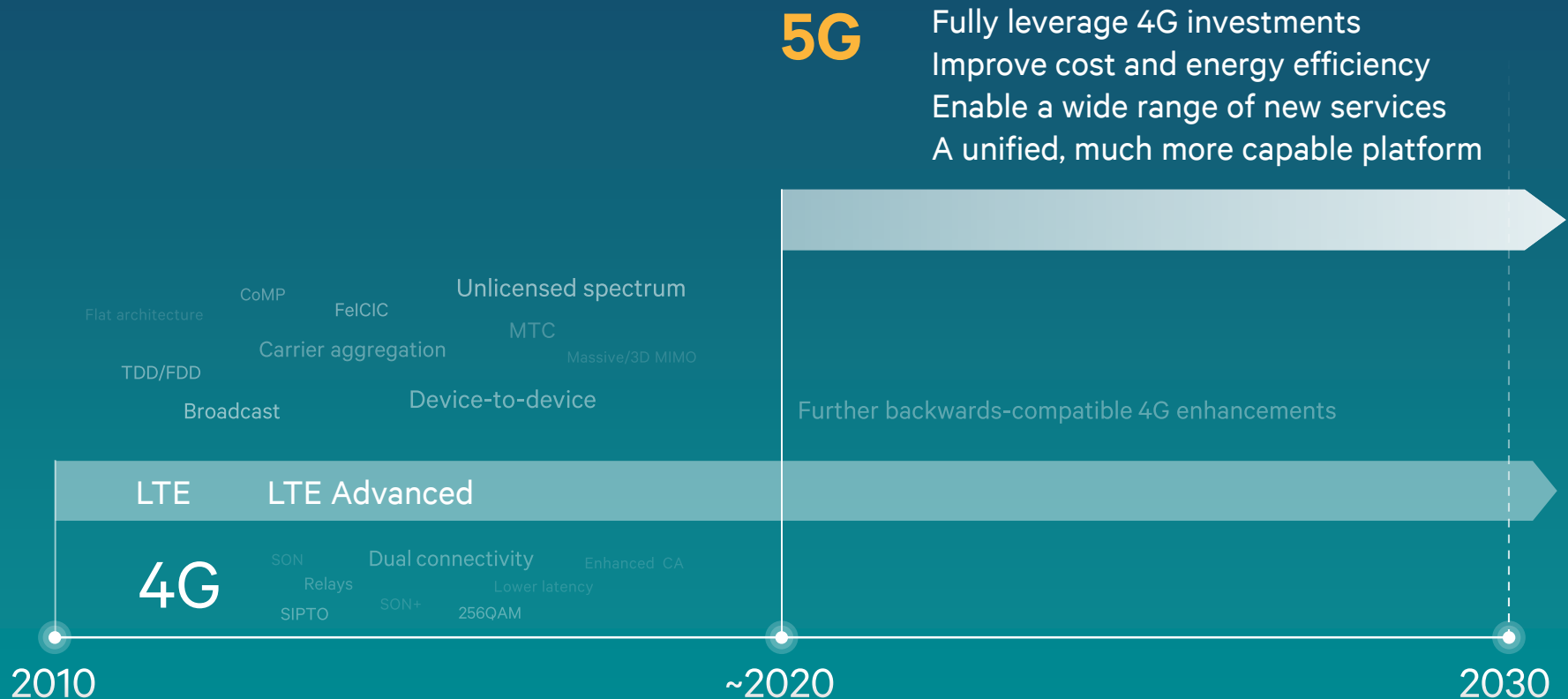
**Below 6 GHz:** mobile broadband, mission critical, and possibly backhaul

**Above 6 GHz including mmWave:** for both access and backhaul, shorter range

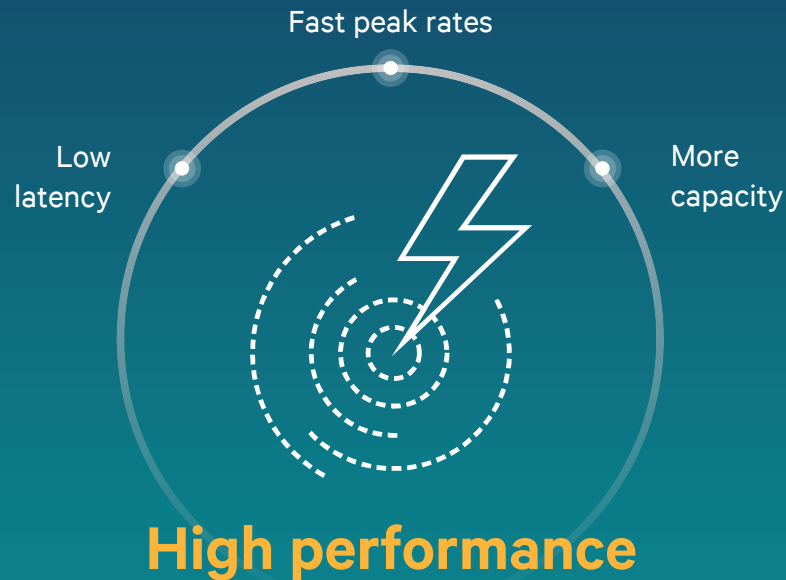
# Multi-dimensional multi-connectivity



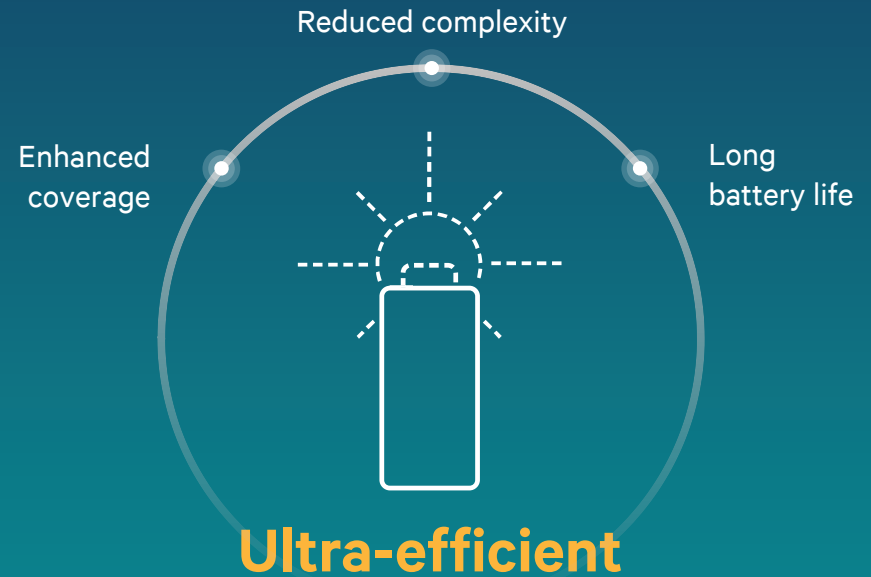
# In parallel: driving 4G and 5G to their fullest potential



# Scaling LTE for the Internet of Things



LTE Advanced CA<sup>1</sup>



LTE Cat-0, LTE-M, C-IOT



# LTE Broadcast

Virtually unlimited number of users can receive same content

## Simulation results



Source: Qualcomm Technologies, Inc. Research. 2GHz carrier frequency, site-to-site distance is 500meter, cluster eMBMS deployment (19 sites in single frequency network), comparison with unicast is based on the same amount of resource allocation.





# LTE Direct

- Scalable
- Universal
- Always-on
- Global



Yoga classes

Social event

Book signing

Used bike for sale

Room for rent

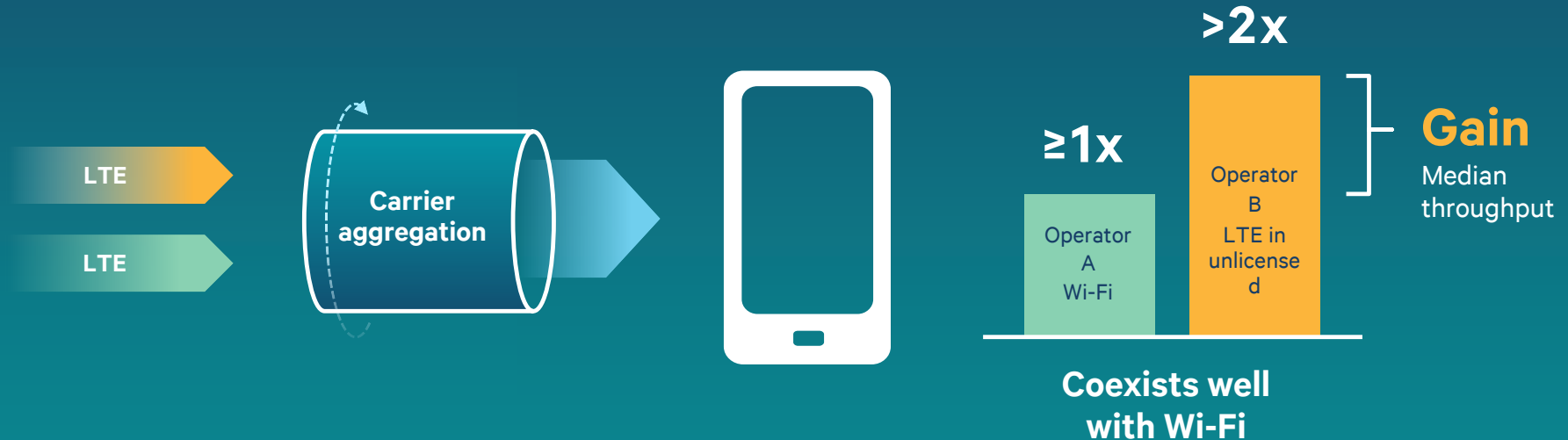
V2V

Free live show

# Aggregating licensed and unlicensed spectrum to deliver greater performance in 4G

## LTE in unlicensed spectrum

(for new small cells using 5GHz)



■ Unlicensed spectrum

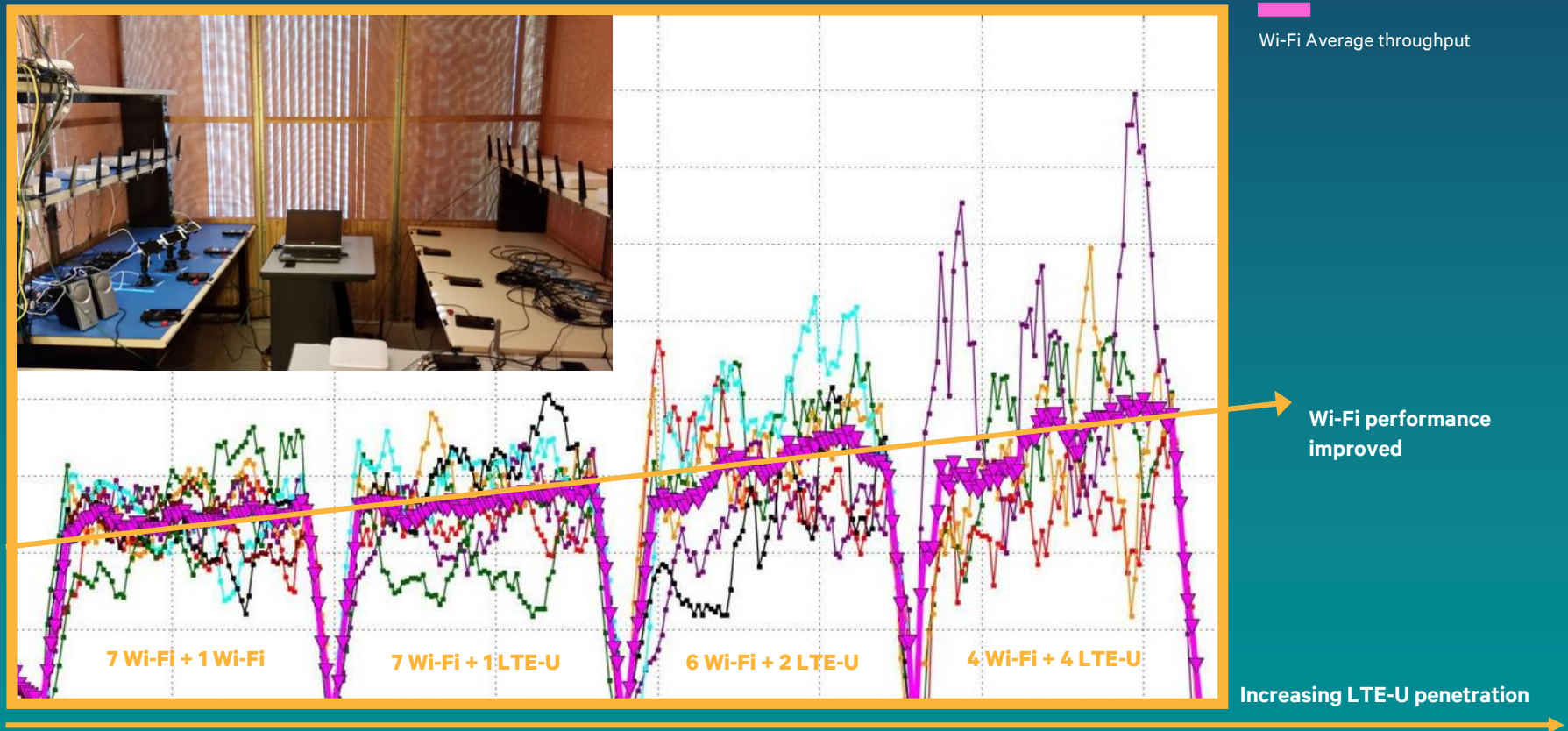
■ Licensed spectrum

Assumptions: Two operators. 48 Pico+108 Femto cells per operator. 300 users per operator with 70% indoor. 3GPP Bursty model. 12x40MHz @ 5GHz for unlicensed spectrum.  
LTE 10 MHz channel at 2 GHz; 2x2 MIMO, Rank 1 transmission, eICIC enabled; LTE-U - Phase II, 2x2 MIMO (no MU-MIMO); Wi-Fi - 802.11ac 2x2 MIMO (no MU-MIMO), LDPC codes and 256QAM).



# LTE-U is a good neighbor – not adversely affecting Wi-Fi

Using adaptive duty cycle (CSAT) for fair coexistence





# MuLTEfire™

LTE-based technology solely for unlicensed spectrum



## 4G LTE-like performance

Enhanced capacity and range  
Improved mobility, quality of experience



## Wi-Fi-like deployment simplicity

Operates in unlicensed spectrum  
Leaner, self-contained<sup>1</sup> network architecture

MuLTEfire is an initiative of Qualcomm Technologies, Inc.

<sup>1</sup> Does not require a traditional core network

# Making the best use of licensed and unlicensed spectrum

## Licensed spectrum

With opportunistic use of unlicensed



### **LTE/LTE Advanced**

(Including LTE-U/LAA,  
LTE/Wi-Fi agg.)

## Unlicensed spectrum

LTE-based technology



### **MuLTEfire™**

## Unlicensed spectrum

802.11 technology



### **Wi-Fi 802.11ac/ad/ax**

# The expanding role of LTE Advanced—a new paradigm

## Scale to connect the Internet of Things



**Carrier Aggregation**  
High performance



Ultra efficient  
**Cat-0, LTE-M**



## Bring new ways to connect & interact

**Evolving the  
LTE Direct Platform**  
Device-to-Device



Multi-hop



Vehicle-to-Vehicle /  
Infrastructure



## Empower new classes of services

Mission-  
critical  
control  
**LTE ULL**



Broadcast  
**LTE  
Broadcast**

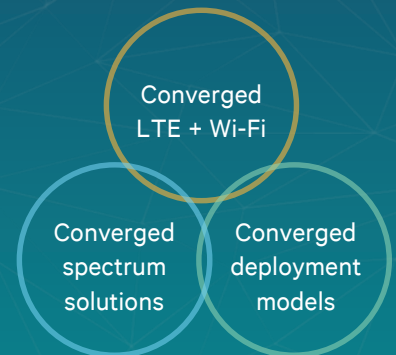
Discovery  
**LTE Direct  
Proximity**



Public Safety  
**LTE Direct  
MCPTT**

## Create a converged connectivity platform

**Link aggregation**



**LTE-U  
and LSA**

**MuLTEfire™**

# Qualcomm fuels major technology shifts in the industry

Anticipating the big challenges and investing early on to solve them

**>\$36B** Cumulative R&D\*

Scorpion CPU  
development initiated

1<sup>st</sup> Android  
smartphone

**Redefined computing**  
From desktop to smartphones

CDMA 3G Standard

**Digitized mobile  
communications**  
From analog to digital

1<sup>ST</sup> WCDMA HSDPA  
multimode chipset

1<sup>ST</sup> LTE Advanced carrier  
aggregation smartphone

1<sup>ST</sup> 64-BIT 3G/  
LTE integrated chip

**Transforming  
the edge of  
the Internet**

LTE/Wi-Fi  
convergence

LTE-U

Machine learning

5G

Computer vision

Security and privacy

\*As of Apr. '15, Qualcomm Technologies, Inc. data



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# Thank you

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